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Long-length Scintillating Fibers for Nuclear Waste Repositories (Conference Record)

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Changing the World's Energy Future

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Idaho National Laboratory

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Long-length Scintillating Fibers for Nuclear Waste Repositories

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Abstract— **This paper describes the fabrication, testing, and characterization of long-length, up to 50 m, scintillating fibers for the purpose of radiation monitoring in inaccessible radiological and nuclear waste repositories. The fabrication aspect was focused on ruggedizing the 1-mm diameter fiber and limiting external light interference for fibers. Testing and characterization were performed in a laboratory setting with radiation sources, a photosensor module and a multi-channel analyzer. Light attenuation was studied as a function of distance by analyzing both the spectrum and count rate. Additionally, the scintillating fibers were coupled to optical communication fibers (100 m) to extend the reach of the system. This paper also includes the optical spectrometry results from the sensitivity and response of the signal attenuation. Lastly, the paper covers the field testing of the scintillating fibers in a relevant environment.**

I. Introduction

THIS research is part of multi-modal sensor system, named TRIPWIRE, for containment verification in inaccessible radiological and nuclear waste repositories at Idaho National Laboratory (INL). The TRIPWIRE system will continuously monitor ionizing radiation and electromagnetic fields in the vicinity of emplaced nuclear materials buried in a repository, reporting on disturbances with a real-time alarm control station. The system will use long-length scintillating fibers to perform area radiation monitoring; these will be coupled to km-scale multimodal optical communication fibers – all light sensors and electronic components used with this system will be located above ground.

II. RADIATION SENSING

Commercial plastic scintillating fibers are usually fabricated in cylindrical shapes with a core of polystyrene and fluor in which the scintillating light is generated through interaction of the incident radiation. The core is surrounded by a thin cladding material which is typically acrylic, more specifically polymethylmethyacrylate. Light rays that arrive at the core-cladding interface with an angle of incidence that is greater than the critical angle for total internal reflection are "piped" down the length of the fiber. Therefore, events occurring near the photomultiplier tube (PMT) undergo less light scattering along the journey resulting in photons with higher intensity than those from events at longer distances which have undergone more scattering [1]. This was seen with the first scintillating fibers used to study light attenuation in this project.

A. Fabrication of Long Fibers

Single 1-millimeter diameter BCF-10 (Saint Gobain) scintillating fibers of 10-m, 20-m, and 50-m total length were fabricated. A step-by-step termination of the ends can be seen in *Fig 1*. The fiber is placed inside a tubing sleeve with light-tight black coating (Thor Labs Inc.). A cap is placed over the tubing end and a SubMiniature A 905 (SMA) connector is connected to the end of the fiber. Heat-shrink tubing is added to hold the connector, cap and tubing together and to prevent light from entering through the connector casing. The end of the fiber is cleaved at the end of the SMA connector. Polishing is required to create a smooth surface at the edge of the connector.

B. Preparation and Testing of Long Fibers

The finished fiber was connected to a Hamamatsu (H10580) PMT and biased at +1570 volts. Upon passing through an amplifier, a shaping time of 0.5 microseconds was applied and connected to the multichannel analyzer (MCA). The MCA data was recorded using ORTEC's Maestro software. A photograph of the set-up can be seen in Fig 2. A 3D printed holder was used to house four Cs-137 sources. This enabled the sources to be at the same distance from the center of the fiber. The holder was used to slide the sources along the fiber without changing their orientation. Measurements were conducted in 1-m increments along the length of the fiber starting from the PMT. Data was recorded with a minimum of 100,000 counts between channels 0 to 500.

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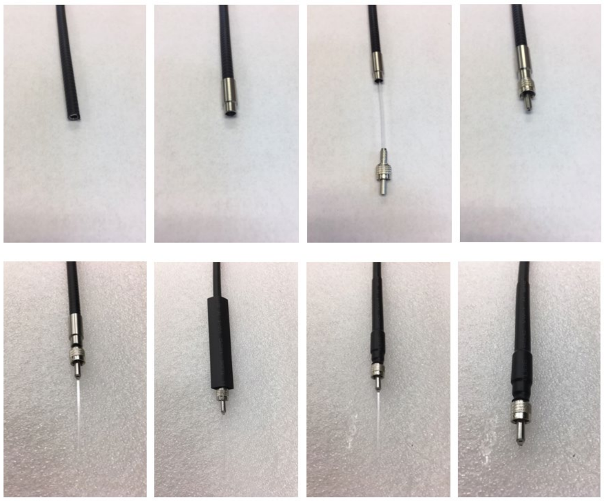

Fig 1. Steps for a scintillating fiber termination using furcation tubing and an SMA-905 connector. This fiber needs to be polished before it can be used.

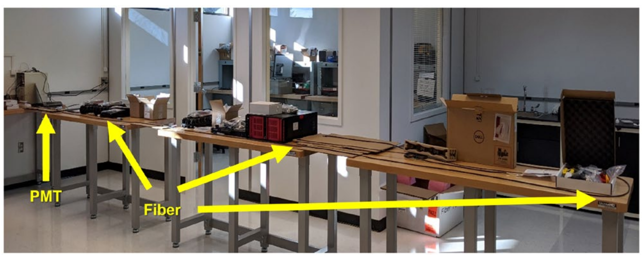

Fig 2. Laboratory bench set-up using a 10-m scintillating fiber.

III. FIBER RESULTS

For the purposes of this summary, only the 10-m fiber data is covered. The results are shown in Fig 3 and include a background measurement to illustrate the net signal recorded towards the end of the fiber opposite of the PMT. At 3-m the number of counts towards the middle of the graph, between channels 150 and 190, is higher as expected due to events occurring closer to the PMT and undergoing less light scattering. At 5-m light scattering increases resulting in photons with lesser intensity, this is seen in the increase of counts below bin 140. As the measurement distance increases, the number of counts decreases resulting in longer acquisition times. The measurement at 9-m had a live time of 1290 seconds.

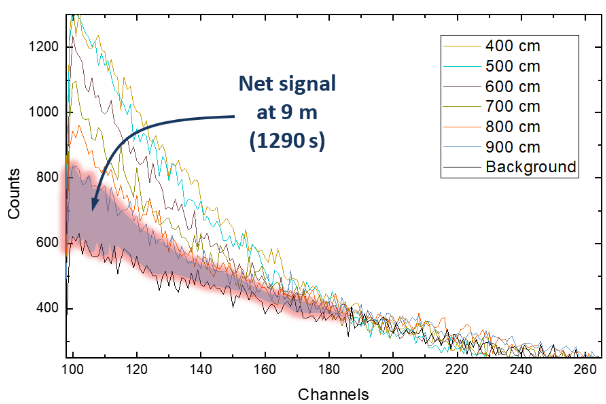

Fig 3. Results of the 10-m fiber measurements for distances above 3-m (from the PMT) with an additional background measurement.

IV. OPTICAL FIBER COUPLING EVALUATION

TRIPWIRE aims to couple scintillating fibers to optical fibers to deploy long-length sensors given the extended tunnel distances in an underground repository. Optical spectrometry was performed to understand the sensitivity and response of the optical fiber couple to a scintillating fiber. A diagram of the set-up used is shown in Fig 4.

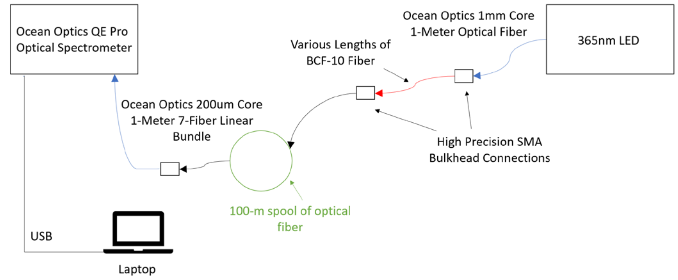

Fig 4. Optical spectrometry set-up diagram with 100-m of 1-mm core optical fiber.

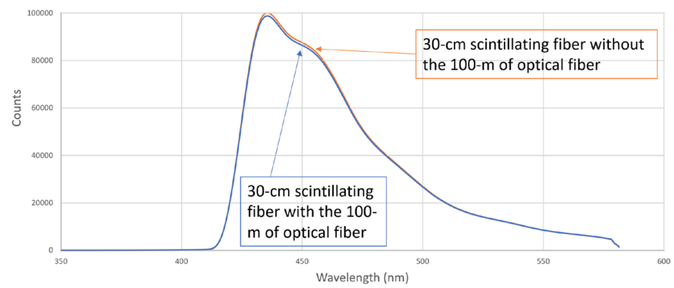

Fig 5. Wavelength comparison of scintillating fiber by itself and connected to 100-m of optical fiber.

V. SCINTILLATING FIBER FIELD TESTING

A. Field Testing Set-up

The Radioactive Scrap Waste Facility (RSWF) south storage area outside the Materials and Fuels Complex (MFC) at INL was selected to perform the field testing due to its periodic changes in configuration and inventory. The RSWF facility contains several interim storage containers (ISC) which measure 2 x 2 x 1.5 meters and have several 50-gallon drums filled with radioactive waste ranging from spent fuel to laboratory waste products.

The previously fabricated fibers were placed across the middle of the facility 1-m away from the ISCs. The 20-m fiber was coupled to 100-m of optical fiber which were placed in a light-tight conduit to avoid external interactions. This set-up is shown in Fig 6. Both fibers were connected to Hamamatsu (H10580) PMTs which were powered via Hamamatsu C7169 power supplies. The data output was connected to Easy-MCA 2k channel multichannel analyzer (AMETEK) and recoded via Maestro (ORTEC) software running on a standard laptop computer. Data was recorded in 60 second intervals.

Fig 6. Field testing deployment of the 50-m scintillating fiber and the 20-m optical fiber coupled to 100-m of optical fiber.

B. Interim Storage Container Movement

The farthest ISC was removed with a forklift from the storage area into the adjacent staging area to add a new 50-gallon drum. A crane lifted the 50-gallon drum out of the overpack cask into the ISC as shown in Fig 7. The drum was reported as 737 mrem per hour on contact. The ISC was closed again and brought back into the storage area to the same location. This enabled a comparison of the total number of counts before and after the transfer.

Fig 7. Placement of a 50-gallon drum with radioactive waste into the fourth position of the ISC.

C. Field Testing Results

The total number of counts for each 60-second spectrum is shown as a function of time in Fig 8. The 50-meter fiber data is shown in blue and the 20-meter fiber in red. The change in the number of counts is correlated with the removal of the ISC which is shown by the drastic drop in total counts in the beginning of the figure. The lifting of the drum from the overpack produced a spike in the total counts and is seen near the middle of the figure. The return of the ISC to its initial location resulted in counts increasing significantly higher than before the removal. These events help illustrate the sensitivity of the scintillating fiber at various distances.

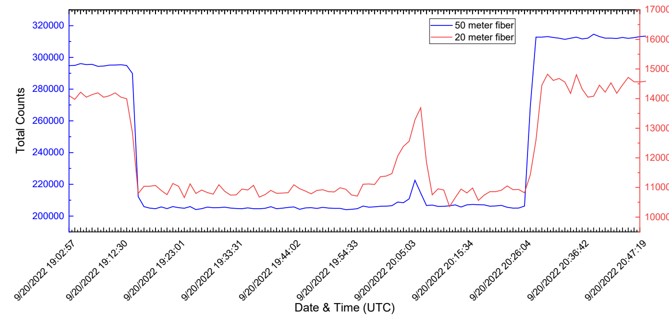

Fig 8. ISC movement results for the two fibers. The 50-meter fiber data is shown in blue and the 20-meter fiber in red.

VI. Conclusion

This summary explains some of the scintillating fiber research performed in support of a multi-modal sensor system for nuclear safeguards. Fibers of 10 and 50 meters were fabricated and tested in the laboratory environment to characterize the number of counts along the length of the fiber. The deployment, field testing, and results shown demonstrate the capability of the technology for monitoring nuclear waste repositories. Additionally, the long-distance and long-length detector concepts based on the coupling of scintillating fibers to optical fibers were confirmed.

Acknowledgment

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[1] G. F. Knoll, "Chapter 8 - Section III.C Fiber Scintillators. In Radiation detection and measurement" Hoboken, NJ, 2010, Wiley (pp. 263-265).